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**Progress Report for Grant NAG 5-2963
Mission Operations and Data Analysis Phase
of the SupraThermal through Energetic Particle detector (STEP)
of the EPACT experiment on the Wind Spacecraft**

Period: Jan. 15, 1996 - Jan. 15, 1997

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1) Summary

During the past year, the major activities performed under this grant were:

- development of data analysis software for STEP
- calibration of STEP for in-flight performance
- scientific studies of energetic particle populations observed by STEP: upstream events, impulsive flares, and corotating interaction regions
- reporting of STEP results at the Schloss Elmau workshop held in Germany in March 1996; and the American Geophysical Union meetings in Baltimore and San Francisco during 1996.
- publications of two papers to *Geophysical Research Letters* as part of a special issue on initial results from WIND; submission of a paper to *Geophysical Research Letters* on upstream 3He, and submission of a paper to *Astrophysical Journal* on solar flare spectra.

2) Science Highlights

a) Upstream ^3He events:

The STEP instrument on the WIND spacecraft observed several upstream events in coincidence with ^3He and Fe-rich solar energetic particle events in late 1994. The distinctive ion composition of the impulsive solar energetic particle population provides an opportunity to study mechanisms that produce upstream events. We reported energy spectra and mass composition of both the upstream event ions and SEP ions as well as the first detection of ^3He ions in an upstream event. The detection of ^3He unambiguously demonstrates that solar energetic particles can undergo further acceleration near the Earth.

b) Upstream events: (general)

The Supra-Thermal through Energetic Particle (STEP) subsystem of the EPACT experiment on the WIND spacecraft observed numerous short duration heavy ion enhancements during the ~9 month period November 1994-September 1995. These enhancements were most frequent and intense when WIND was close to the magnetosphere, but were often observed also during the period when the spacecraft was $>100 R_E$ upstream. The events occur in association with high speed solar wind streams that are signatures of corotating interaction regions (CIRs). A typical event observed on January 31, 1995 when WIND was $195 R_E$ upstream showed strong field aligned anisotropies and rapid time variations. Heavy ion abundances near 45 keV/nucleon were $\text{He:C:O:Fe} = 138 : 1.46 : \approx 1 : 0.12$, very similar to those observed at higher energies in corotating streams, and distinctly different from magnetospheric ring current abundances measured on the AMPTE spacecraft. We suggest that the CIRs provide the seed population for these heavy ion events, which are then further accelerated in association with the Earth's bow shock.

c) Energy spectra of ions accelerated in impulsive and gradual solar events

We reported new high-sensitivity measurements of the energy spectra of ions from five impulsive solar flares and one gradual event observed during solar

minimum by the EPACT instrument on WIND. All of the impulsive-flare events had intensities too low to be visible on previous spacecraft such as *ISEE-3* which observed hundreds of impulsive-flare events. Often these events cluster in or behind a coronal mass ejection (CME) where the magnetic field lines provide an excellent connection to a solar active region where flares are occurring. In most cases we can see velocity dispersion as the ions of 20 keV/amu to 10 MeV/amu streamed out from the impulsive flare at the Sun, arriving in inverse order of their velocity. Ions from a large, Magnetically well-connected gradual event, associated with a CME-drive shock, also show velocity dispersion early in the event, but show identical time profiles that last for several days late in the event. These time-invariant spectra of H, ^4He , C, O, and Fe in this gradual event are well represented as power laws in energy from 20 keV/amu to ~ 100 MeV/amu. In the impulsive-flare events, H, ^3He , ^4He , C, O, and Fe have more rounded spectra that flatten somewhat at low energies; yet the intensities continue to increase down to 20 keV/amu.

d) Impulsive Solar Particle Events

During the first 10 months of WIND observations, we detected several time periods with energetic particle abundances that are characteristic of impulsive flares: enrichments in the ^3He isotope, and in heavy ions compared to the corona. Using the Supra-Thermal through Energetic Particle sensor on WIND, we found that at ~ 100 keV/nucleon these events typically arrive in sequences of multiple events when the spacecraft is magnetically connected to an active region at western solar longitudes, preceding the arrival of a high speed solar wind stream. During recurrent high speed solar wind streams with their associated flux enhancements Fe-rich events are seldom seen: almost all of the events occurred on days with solar wind speeds < 450 km/sec. The impulsive events we observe arrive at a rate of ~ 30 events/year at solar minimum for energies ≥ 120 keV/nucleon. This rate is comparable to upper limits placed on the observed rate of higher energy ^3He -rich events in the last solar minimum with measurements from *ISEE-3*.

e) Corotating Interaction Regions

We measured the time variations of the energetic particle composition at ~180 keV/Nucleon within several high speed solar wind streams with the EPACT/STEP instrument on the WIND spacecraft. We find that Fe/O decreases with time after the stream interface, while He/O, C/O, and Ne-S/O tend to be constant. Corotating interaction regions were first identified as recurrent increases in H and He fluxes with 27-day period in 1965 solar minimum in association with high speed solar wind streams. Simultaneous observations during 1975 solar minimum at 0.3-10 AU showed higher intensity beyond 1AU and sunward streaming in SW frame. Likely sites for this particle acceleration are forward and reverse shocks that bound corotating interaction regions (CIRs). 1 AU ion enhancements rarely seen in slow solar wind proceeding the high speed stream.

On the high speed side of the stream interface we found:

- He/O and C/O tend to be constant and are consistent with previous solar wind and energetic particle measurements in high speed streams
- Fe/O tends to decrease to a value of ~0.05, consistent with coronal hole Fe/O measured by AMPTE/CHEM and ~3 times lower than slow solar wind Fe/O.

Previous measurements of energetic particle abundances, together with these new observations of the abundance variations with time, suggest that the energetic particles within the high speed streams are accelerated out of the solar wind plasma at corotating reverse shocks.

Summary Bibliography

Journal Publications:

1. von Rosenvinge, T. T., L. M. Barbier, J. Karsch, R. Liberman, M. P. Madden, T. Nolan, D. V. Reames, L. Ryan, S. Singh, H. Trexel, G. Winkert, G. M. Mason, D. C. Hamilton, and P. H. Walpole, "The energetic particles: acceleration, composition, and transport (EPACT) experiment on the Wind spacecraft", *Space Sci. Rev.*, 71, 155-206, 1995.
2. Mason, G. M., J. E. Mazur, and T. T. von Rosenvinge, "Energetic heavy ions observed upstream of the Earth's bow shock by the STEP/EPACT instrument on WIND", *Geophys. Res. Letters*, 23, 1231-1234, 1996..
3. Mazur, J. E., G. M. Mason, and T. T. von Rosenvinge, "Fe-rich solar energetic particle events during solar minimum", *Geophys. Res. Letters*, 23, 1219-1222, 1996
4. Reames, D. V., L. M. Barbier, T. T. von Rosenvinge, G. M. Mason, J. E. Mazur, and J. R. Dwyer, "Energy spectra of ions accelerated in impulsive and gradual solar events", *Astrophysical J.*, submitted September, 1996.
5. Dwyer, J. R., G. M. Mason, J. E. Mazur, and T. T. von Rosenvinge, "Acceleration of solar flare ^3He at the Earth's bow shock", *Geophys. Res. Letters*, submitted September 1996.

Papers Presented at Conferences:

1. von Rosenvinge, T. T., L. M. Barbier, D. V. Reames, G. M. Mason, and D. C. Hamilton, "First results from the energetic particle acceleration, composition, and transport investigation on the WIND spacecraft", (25 min.), *Trans. Am. Geophys. U.*, 76, S218, 1995.
2. Salter, E. C., G. M. Mason, J. E. Mazur, D. V. Reames, and T. T. von Rosenvinge, "Composition and energy spectra of upstream events observed by the EPACT instrument on Wind", *Trans. Am. Geophys. U.*, 76, S218, 1995.
3. Reames, D. V., J. E. Mazur, G. M. Mason, and T. T. von Rosenvinge, "Helium spectra in corotating energetic particle streams observed by EPACT on the Wind spacecraft", *Trans. Am. Geophys. U.*, 76, S218, 1995.
4. Mazur, J. E. and G. M. Mason, SAMPEX observations of corotating ion events at 1 AU, *Proc. 24th Internat. Cosmic Ray Conf. (Rome)*, 4, 459, 1995.

5. Mazur, J. E., G. M. Mason, D. V. Reames, and T. T. von Rosenvinge, Helium spectra in corotating energetic particle streams observed by EPACT on the Wind spacecraft, *Proc. 24th Internat. Cosmic Ray Conf. (Rome)*, 4, 460, 1995.
6. Mason, G. M., J. E. Mazur, D. V. Reames, and T. T. von Rosenvinge, "³He-rich solar energetic particle events during solar minimum", *Trans. Am. Geophys. U.*, 76 (Suppl.), F470, 1995.
7. Dwyer, J. R., G. M. Mason, and J. E. Mazur, "Ion events observed upstream of the Earth's bow shock by the STEP/EPACT instrument on Wind", *Trans. Am. Geophys. U.*, 76, (Suppl.), F473, 1995.
8. Mazur, J. E., and G. M. Mason, "The composition and energy spectra of >20 keV/nucleon ions in corotating particle streams: WIND/EPACT observations", *CIR workshop at Schloss Elmau*, Elmau, Germany, March 11-15, 1996.
9. Dwyer, J. R., G. M. Mason, and J. E. Mazur, "Upstream ion events from the Earth's bow shock observed by the STEP instrument on WIND", *Trans. Am. Geophys. U.*, 77, S222, 1996.
10. Reames, D. V., T. T. von Rosenvinge, G. M. Mason, J. E. Mazur, and J. R. Dwyer, "WIND/EPACT spectra of energetic particles from impulsive solar flares", *Trans. Am. Geophys. U.*, 77, S206, 1996.
11. Mason, G. M., J. E. Mazur, J. R. Dwyer, D. V. Reames, and T. T. von Rosenvinge, "Composition and energy spectra of CIR heavy ions observed near Earth during the current solar minimum", (Invited Talk, 15 min) *Trans. Am. Geophys. U.*, 77, S222, 1996.
12. Dwyer, J. R., G. M. Mason, J. E. Mazur, and T. T. von Rosenvinge, "Temporal variations of CIR heavy ion intensities below 1 MeV per nucleon", *Trans. Am. Geophys. U. (Suppl.)*, 77, Fxxx, 1996.
13. Mason, G. M., J. E. Mazur, J. R. Dwyer, D. V. Reames, and T. T. von Rosenvinge, "Low energy CIR heavy ions: abundance anomalies and new spectral features", *Trans. Am. Geophys. U. (Suppl.)*, 77, Fxxx, 1996.

Meetings Attended to Report STEP Science Results and Collaborate with WIND Science Team Members:

- 1) Spring 1995 American Geophysical Union Meeting, Baltimore, MD, May 1995
- 2) 23rd International Cosmic Ray Conference, Rome, August/September 1995
- 3) WIND Science Working Team Meeting, Greenbelt, MD, October 1995
- 4) Fall 1995 American Geophysical Union Meeting, San Francisco, December 1995
- 5) Low Energy Particles experimenter's subgroup (ESSA experiment) meeting, Berkeley CA, December 1995.
- 6) Corotating Interactions Workshop, Schloss Elmau, Germany, March 1996.
- 7) Spring 1996 American Geophysical Union Meeting, Baltimore, MD, May 1996
- 8) Fall 1996 American Geophysical Union Meeting, San Francisco, December 1996 (papers submitted & accepted at current writing 11/96).